Time Evolution of the Density Field of a Micro–Explosion Using Background Oriented Schlieren

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1 Introduction

In recent years micro-explosions have found interesting trans-disciplinary applications in the areas of food preservation, wood science, drug delivery, gene therapy and bio-medical applications [1, 2]. Generating controlled micro-explosions in a laboratory environment in a reliable manner is essential; to study and understand some of the near field flow dynamics associated with blast waves. The blast waves are produced by sudden release of energy normally characterized by a supersonic shock front followed by an exponential type decay of the physical properties like overpressure of the gas as it expand spherically. The flow field associated with the blast wave is non-isentropic in nature which implies that properties like over pressure, density and velocity have to be measured independently. The micro-blast provides a challenging case for the application of novel flow diagnostic techniques, to measure flow properties.

The complete mapping of the density field around such a micro-explosion has been successfully carried out by Suriyanarayanan et al.[4] and Venkatakrishnan et al[7] using BOS technique. These attempts with BOS succeeded in capturing the instantaneous density field measurement at discrete time instants. However, this does not allow a full description of the time evolution of the flow as there is some time jitter associated with the flow initiation resulting in some small irreproducibility with time. This study uses BOS technique along with a high speed camera to capture the time evolution of the micro-explosion. This is challenging in terms of illumination and imaging especially with the high intensity flash of the blast. The results will be useful in model validation for CFD simulation tools and at understanding the basic physics associated with explosive driven shock wave propagation.

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2 Experimental Description

2.1 Micro-Explosion generator

The micro-explosion is generated at the open end of a non-electrical (NONEL®) tube (M/s Dyno Nobel, Sweden), an explosive transfer system similar to that used by Obed et al. (2012) [3]. The system consists of a plastic tube of approximately 1.8 mm inner diameter and 3 mm outer diameter with a thin layer of explosive material coating (HMX with traces of aluminum 18 mg/m length of the polymer tube) deposited on its inner wall of the tube. The ignition of the NONEL® tube was done using NONEL Dynostart®, an electronic blasting device in which electrical energy is converted into a powerful spark. It consists of an energy source (battery), a voltage converter, a capacitor for energy accumulation (2500V approx), an electrode and push buttons to effect initiation. The electrode emits a spark into the inner surface of the NONEL® tube to initiate the ignition of the explosive coating.

The ignition of the reactive material coated on the inner surface of the NONEL® tube results in the formation of a combustion wave. The combustion wave also heats up the gases in the tube. The dispersed energetic material is heated and then combusted to release energy which supports the shock front at a typical rate of 2000 m/s [3] . The detonation is confined to the plastic tube along its length and the products of combustion are allowed to escape from the open end of the tube. These products of combustion are at higher pressure than the ambient and due to its sudden expansion at the open end results in the formation of a blast wave.

2.2 Background Oriented Schlieren (BOS) methodology

The principle of the technique is the refractive index variation due to density gradients in the flow. The determination of the density field using BOS thus involves the following steps: (a) calculation of displacements in the background which is imaged through the flow of interest. This is done through a (in-house) PIV-type cross-correlation algorithm. These displacements are the vectors of density gradient at each point; (b) calculation of the line-of- sight integrated density field by solution of the Poisson equation, which is the gradient of the above displacement; (c) use of optical tomography (filtered back-projection) to determine the density field in the actual plane of interest. The reader is referred to Venkatakrishnan and Meier [5] for a derivation of the reconstruction function. The reconstruction of the entire field is achieved by inverse tomography [6].

2.3 Experimental setup

A Phantom V711 camera is used to image the flow with Nikon 70-210 mm lens used as the imaging optics. Illumination is carried out using two halogen lamps behind the background dot pattern. The dot pattern used for the study has a resolution of 3000 dpi. PCC® (proprietary software of Phantom Vision Research) is used for image acquisition and IDT proVISION® software is used for post processing of the images to get the density gradient field. The image is acquired at 100,000 frames per

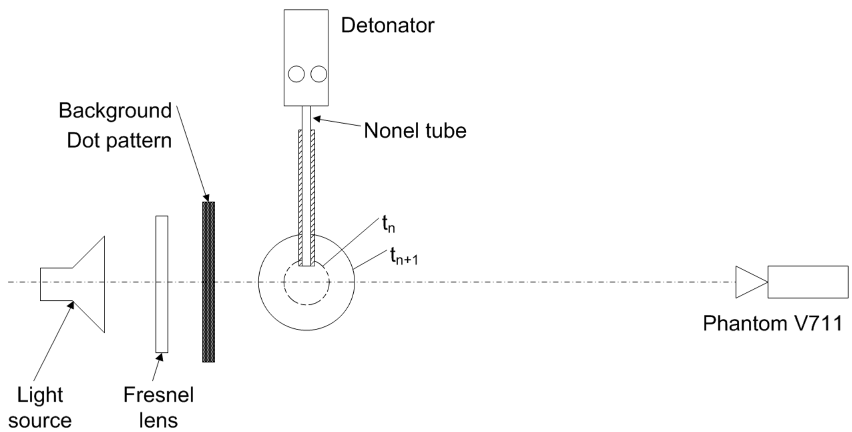

Fig. 1 Schematic of the experimental set up

second while both the camera and the detonator are manually triggered at the same time. This implies that the density field is available after every 5mm (approx.) of movement. The NONEL® tube is cut to a length of 230mm in length and inserted into the stainless steel tube of inner diameter 3mm as shown in the Figure 1. The tube is kept at a distance of 3.5 m from the camera and 150 mm from the background to get maximum sensitivity. The experimental set up is based on the Qioptiq® optical table to prevent any unwanted vibrations due to the micro-explosion.

3 Results and Discussions

The Figure 2 shows the raw image taken at no-flow condition and image taken at flow condition. In order to get meaningful density gradient field a minimum resolution of 256 x 200 pixels is required and this limits the camera framing rate to 100,000 frames per second. The exposure of the camera is kept at 3μs. In addition to the displacement of the blur there is still remnant of the flash of explosion. Figure 3 and 4 shows the gradients of the mean line-of-sight integrated density field obtained by correlation of no-flow and flow images. The vectors point in the di-

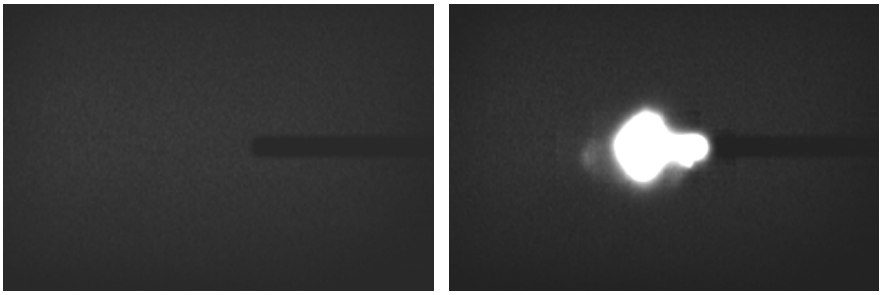

Fig. 2 Background dot pattern in no-flow and flow condition

rection of lower density and are color-coded to show the varying magnitude of the gradients that correspond to bi-directional Schlieren. As in the continuous Schlieren the growth and evolution of the blast wave is well captured. The smaller exposure of the camera helps in capturing the flow structures inside the core, which was lost during the previous experiments [4, 7]. The spatial resolution of the density gradient

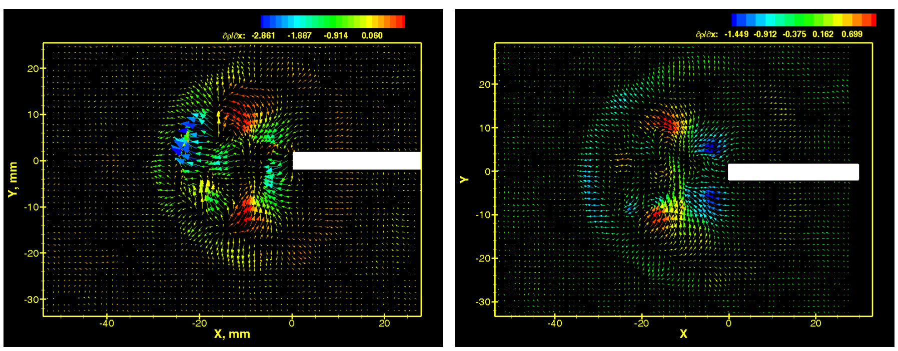

Fig. 3 Density gradient field at t = 35μs and t = 45μs

field is low due to the lower resolution of the camera which limits the resolution of flow structure being captured. The blast wave radius is compared with the earlier experiments and the trend is captured well and matching well as seen in Figure 5.

4 Conclusion

Time evolution of the density field of a micro-explosion is captured using the high speed BOS technique. The flow structure near the core is captured due to the shorter exposure of the camera which was not possible in the earlier efforts that used dis-

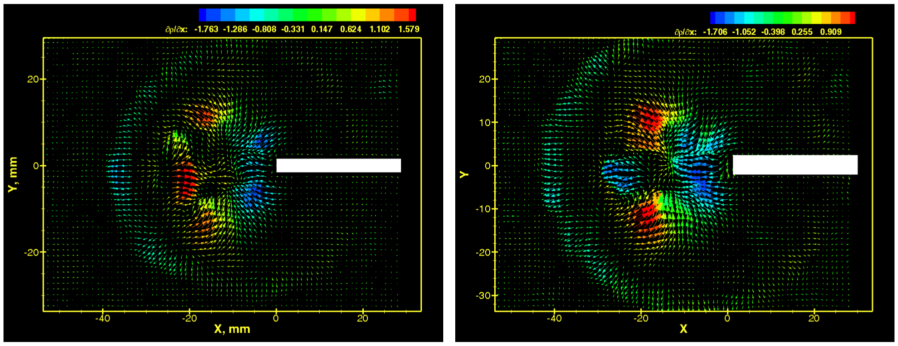

Fig. 4 Density gradient field at t = 55μs and t = 65μs

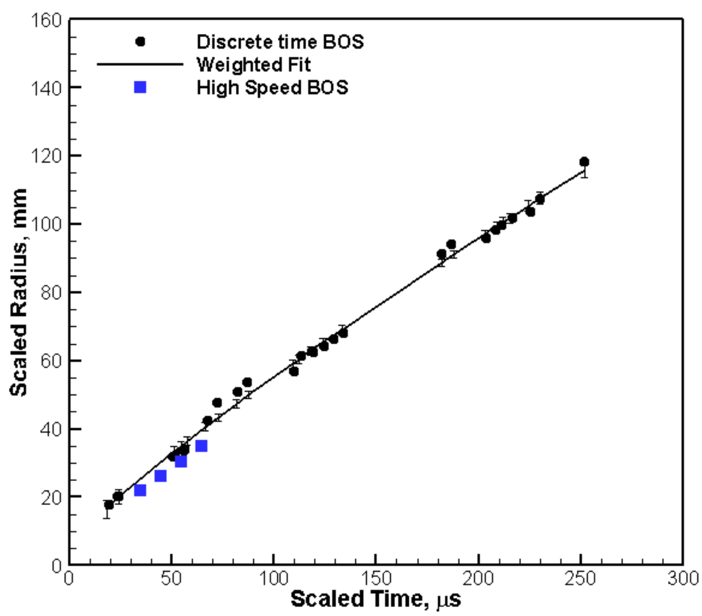

Fig. 5 Comparison of radius obtained with high speed BOS and discrete time BOS

crete single shot cameras. However, the lower spatial resolution of the high speed camera was unable to capture the finer details of the turbulent core. The study shows the usefulness of capturing the time evolution of the density field. Such data can be enormous help in validating CFD models.

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